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<p>(54) Title: APPARATUS AND METHODS FOR CUTTING SOIL AND IN SITU CONSTRUCTION OF SUBSURFACE CONTAINMENT BARRIERS</p>		
<p>(57) Abstract</p> <p>An apparatus for cutting soil and constructing containment barriers, such as for constructing a subsurface containment walls or bassins for contaminated material, comprises a beam (4) pivoted to a support (6) on the surface for abutting an extended length of soil (2a). The beam (4) comprises a cutting means for creating a cutting action against the extended length of abutting soil. The cutting means is preferably a conduit containing a plurality of jet ports through which high pressure fluid is ejected to impact the soil to be cut. The conduit is preferably rapidly reciprocated. As cutting occurs, the beam (4) and the conduit pivot relative to the support to maintain the cutting apparatus adjacent the face of the soil (2a) to be cut. If the support is mobile, it can advance the cutting action by pulling the beam and conduit beyond the sector through which the beam (4) and conduit can pivot. A method of cutting soil comprises generating cutting action along an extended locus of soil, and advancing the cutting action along a descending locus of the soil (2a) in response to gravity.</p>		

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10 **APPARATUS AND METHODS FOR CUTTING SOIL AND IN SITU
CONSTRUCTION OF SUBSURFACE CONTAINMENT BARRIERS**

15 This invention relates generally to apparatus and
methods for cutting soil and constructing subsurface
containment barriers in place. Although not necessarily
limited to the following, the present invention has
particular application in simultaneously cutting through
20 a subsurface volume of soil and emplacing a cement slurry
to construct in situ a continuous subsurface wall,
horizontal panel or basin around and under a hazardous
waste site.

25 There are many automated ways of cutting or
excavating soil (soil as used herein refers to any ground
or subsurface material to be cut or excavated). For
example, there are scooping devices such as backhoes and
clamshells; there are drilling devices such as augers;
30 and there are blasting devices such as dynamite and high
pressure fluid. Of particular interest to the present
invention as used in the aforementioned exemplary
application, however, are the devices and techniques used
for cutting soil in the environmental remediation
35 industry.

In the environmental remediation industry it is
often desirable to form an impermeable underground
containment wall to contain contaminants which are

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present in the soil and water, thereby preventing or
impeding further migration of the contaminants.
Hazardous waste sites frequently contain hundreds of
thousands of cubic yards of materials which represent a
5 long term threat to ground water quality. While on site
treatment is a preferred means of eliminating this
threat, this is not always feasible. At some sites the
cost of physically removing the material and placing an
impermeable liner in the vacated cavity is beyond the
10 resources of the site owner. Sites with buried drums,
radioactive dusts, or other airborne hazards may become
much more dangerous if excavated. There are also cases
where vast and deep areas are only slightly contaminated
and require only a containment action. Existing
15 containment technologies provide the means to place a
wall around the perimeter of a site or to place a cap
over a site.

One common method of constructing a side containment
20 wall is by slurry trenching. This method digs a trench
and emplaces a bentonite (clay) slurry as the trenching
proceeds. Once the trench is dug, the slurry is replaced
with concrete or bentonite modified clay. This technique
tends to be slow and very costly at depths exceeding 40
25 feet. This technique is also limited to forming a
relatively wide (e.g., 36 inches) wall even though it is
only the thin filter cake build up on the wall that acts
as a permeability barrier. The difficulties and expense
of forming and ensuring that a continuous wall has been
30 formed increases dramatically below a 40 foot depth, a
depth below which this type of wall often needs to
extend.

Hydraulic soil cutting using jet grouting is another
35 technique used in the environmental remediation industry.
Although this is a useful technique, it is not

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particularly efficient because much of the jet energy is wasted in passing through fluid before impacting the soil. This causes low production rates, and the cost of the process tends to be higher than for mechanical methods. In most forms of jet grouting it is also difficult to verify that a continuous wall has been formed because the wall is formed from a series of overlapping columns rather than in a continuous fashion. This makes it difficult to form containment walls deeper than 40 feet using this technique.

For forming deeper walls, a four-auger drill system and a clamshell digging tool have been used. The four-auger system is very expensive and slow, capable of forming only 20 to 30 linear feet of wall per day. Clamshell excavating techniques are also very slow.

The foregoing techniques typically provide vertical walls. They do not typically provide bottom barriers under the site, but rather they rely on having a natural layer of low permeability soil (e.g., impermeable rock or clay) underlying the waste site to complete the containment envelope. We are, however, aware of two prior ways of creating an underlying barrier.

Jet grouting technology as practiced by Halliburton Services of Duncan, Oklahoma allows a bottom to be installed by drilling vertical holes and using the jet grouting process to form overlapping disks of treated material at the bottom elevation. Just as with side wall jet grouting referred to above, it is difficult to verify the integrity of the resulting underlying barrier. Another technique uses horizontal drilled holes with liquid nitrogen freezing. This has quality control problems and requires continuous maintenance. Near surface horizontal pancake fracturing or "block heaving"

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is another technique which seems to work, but it is difficult to control quality with this technique.

For very large sites containing enormous volumes of waste such as are found in the mining industry for example, the primary, if not the only, suitable technique of waste containment of which we are aware is to physically move the waste onto a synthetic liner and place a cap over it. This has detrimental cost and environmental impact shortcomings as referred to above.

Although the foregoing techniques may be effective in particular applications, they have at least the shortcomings noted above. What is lacking is a cost effective technique for cutting soil to facilitate at least the deep construction of contaminated soil impoundment walls and subsurface containment barriers having high structural integrity around and under waste sites without moving the waste.

The present invention overcomes the above-noted and other shortcomings of the prior art by providing a novel and improved apparatus and method for cutting soil for in situ construction of impoundment walls and/or subsurface containment barriers. The apparatus and methods enable the faster, more efficient and more economical construction of subsurface walls, such as contaminated soil impoundment walls and containment barriers which can extend well below 40 feet into the earth.

In a preferred embodiment, the present invention utilizes both hydraulic and mechanical excavation techniques, but either one can be used alone. This preferred embodiment includes a long beam that is joined by a hydraulic reciprocating member to a pivot joint on the frame of a crane. Within the beam is a tubular

5 conduit which conveys high pressure slurry from an external mixing/pumping unit. At least a portion of the conduit has a plurality of small holes or jet ports which direct the energy of the high pressure slurry toward the face of the soil to be cut. In this particular embodiment the conduit is reciprocated lengthwise so that the jets of slurry contact all the soil in the path of each stroke.

10 The beam of this preferred embodiment is dense enough so that it is not buoyant in any fluid or loose mixture it might encounter. Accordingly, as each stroke of the conduit is completed, the conduit's weight causes it to sink or fall downward and forward to position
15 itself automatically for the next cut. As this occurs, the crane moves along the ground so that the advancing conduit is pulled through an extended volume of soil which is cut as the apparatus advances. These actions maintain the jets positioned right at the face of the
20 soil to be cut; therefore, the pressurized fluid exiting the jets does not have to pass through much if any intervening fluid before it impacts the soil. Thus, little energy is lost prior to impacting the soil.

25 In a preferred embodiment for forming a containment barrier, the present invention uses reciprocating high pressure jets of hardening fluid to cut through the soil along a path from one side of a waste site to another without passing through the waste material itself. As
30 the fluid cuts the soil, it also mixes with the soil and subsequently hardens; thus, the high pressure jets, or jet streams, provide both the necessary energy and material for disrupting the soil and forming the barrier. The path traversed by the reciprocated jet is moved
35 transversely so that it passes under the site from one end of the site to the other. As a result, an

impermeabl containment barrier sheet in the nature of a basin is formed in situ both around and under the waste site. The resulting barrier should have high structural integrity because it is formed in a continuous manner.

5 It is also contemplated that this technique should be cost effective for constructing in situ surface barriers, or of partial containment barriers which prevent underground contamination in moving in a particular direction.

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The present invention also provides a method of cutting soil, comprising: generating cutting action along an extended locus of soil; and advancing the cutting action along a descending locus of the soil in response to gravity. Generating cutting action can include
15 individually or in combination pumping a fluid through a conduit having a plurality of ports through which the fluid is ejected into the soil adjacent which the conduit is disposed, reciprocating the conduit while pumping the
20 fluid, or reciprocating a beam along the extended locus of soil. The method can also comprise advancing the cutting action horizontally from the descending locus.

The apparatus of the present invention can be used
25 for constructing a subsurface basin in soil. This apparatus comprises means for creating in situ a continuous cross-sectional portion of the subsurface basin. The means includes a conduit adapted to be disposed in the soil along at least a portion of a locus
30 extending into the soil from two locations at the upper surface of the soil and lying across a cross-sectional area of the basin. The conduit has at least one opening for ejecting fluid under pressure into the soil. The apparatus further comprises means for moving the conduit
35 transversely to the locus.

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Th pres nt invention provides an apparatus particularly suitable for constructing a containment barrier around and under a waste site disposed in soil, which apparatus comprises: means for cutting a continuous
5 elongate trench through the soil under the waste site and preferably from one side of the waste site to another side of the waste site without intersecting the waste site; means for displacing the means for cutting through the soil so that the elongate trench is extended
10 transversely to itself across a continuum along and under the waste site; and means for placing a barrier material in the transversely extended elongate trench.

The present invention also provides a method of
15 constructing a subsurface barrier, which method comprises: (a) cutting into soil along a continuous locus extending into the soil from two locations on the surface of the soil; (b) simultaneous with step (a), emplacing a fluidized barrier material in the cut soil; and (c)
20 repeating steps (a) and (b) throughout a continuum between a first such locus and a second such locus.

Therefore, from the foregoing, it is a general object of the present invention to provide a novel and
25 improved apparatus and method for cutting soil for constructing in situ impoundment walls and containment barriers. Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art when the following
30 description of the preferred embodiments is read in conjunction with the accompanying drawings.

FIG. 1 is a schematic diagram of a preferred embodiment of the present invention.

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FIG. 2 is an illustration of a particular implementation of the apparatus represented in FIG. 1.

5 FIG. 3 is a perspective view of a preferred embodiment of a portion of a beam and conduit of the particular implementation shown in FIG. 2.

10 FIG. 4 is a side view of hydraulic cylinders connected to the beam for reciprocating the beam and the conduit mounted on the beam.

15 FIG. 5 is another side view, partially in section as marked by line 5-5 in FIG. 4, of the hydraulic cylinders shown in FIG. 4.

FIG. 6 is a cross-sectional illustration of a multiple beam assembly which can be used in the apparatus illustrated in FIG. 1.

20 FIG. 7 is a schematic illustration of a beam and conduit assembly wherein only the conduit is reciprocated as the beam and conduit advance through the soil.

25 FIG. 8 is a schematic perspective view of a containment barrier basin of a type contemplated to be formed with the present invention.

30 FIG. 9 is an illustration of a particular implementation of the present invention suitable for constructing the barrier illustrated in FIG. 8.

35 FIG. 10 is a perspective view of a preferred embodiment of a fluid jetting and support structure more generally shown in FIG. 9.

FIG. 11 is an illustration of another particular implementation of the present invention.

5 FIG. 12 is an illustration of a further particular implementation of the present invention.

10 FIG. 13 is a sectional view, as taken along line 13-13 in FIG. 12, of a conduit and stabilizer of the implementation shown in FIG. 12.

FIG. 14 is an illustration of a preferred embodiment for cutting soil and forming subsurface containment barriers.

15 FIG. 15 is an illustration of the pivot point between the beam and boom of FIG. 14.

FIG. 16 is an illustration of the jet port area of FIG. 14.

20 FIG. 17 is an illustration of the end jet port area of FIG. 14.

Referring to FIG. 1, the present invention broadly includes means for abutting soil 2 in response to gravity, and means, connected to the means for abutting, for creating a cutting action against the abutted soil. The means for abutting of the embodiment depicted in FIG. 1 includes a falling beam 4 which is shown pivotally connected to a support 6 on the surface of the soil 2; however, the means for abutting can be implemented in other ways as will be further referred to hereinbelow. The means for creating a cutting action can also be implemented in any of various different ways. One of these includes a source of pressurized fluid 8 represented in FIG. 1. Presently contemplated

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implementations of these elements will be further described hereinbelow.

The equipment shown in FIG. 2 is a particular implementation of the apparatus represented in FIG. 1. The beam 4 (see also FIG. 3) is a linear series of interconnected H-shaped steel members 10. Steel plates 12 are bolted to adjacent members to hold them together. This permits on-site fabrication of selected lengths of beams. The members 10 are intrinsically heavy enough or are filled in a central cavity with a weight-increasing material (e.g., high density concrete 14 as illustrated in FIG. 3) to ensure that the beam 4 automatically sinks in response to gravity as the soil 2 is cut. More generally, the beam 4 is constructed so that it is not buoyant in any fluid or loose mixture it encounters as the soil 2 is cut in accordance with the present invention. FIG. 2 shows the beam 4 adjacent face 16 of initially uncut soil 2a after the apparatus has passed through cut soil 2b due to the cutting action and automatic advancing of the present invention.

The beam 4 of the FIG. 2 embodiment has opposed channels 18, 20 (see FIG. 3). A conduit 22 of the means for creating a cutting action is supported by the beam 4 in these channels as shown in FIG. 3. The conduit 22 includes tubular members having a plurality of small (e.g., about 2 to 6 millimeter) ports or jets 24 along the portion of the conduit 22 facing the soil 2. The conduit 22 conducts fluid under high pressure from the source 8 to the jets 24 so that the fluid is ejected from the jets at high velocity to cut the soil impacted by the fluid. An example of a particular fluid source 8 includes a known type of cement mixing and pumping truck 26 receiving bulk materials in a known manner from a trailer 28 (such a truck and trailer can be provided by

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Halliburton Services of Duncan, Oklahoma). A fluid circulating circuit is formed by connecting the two ends of the conduit 22 to two hoses 30, 32 from the truck 26 as depicted in FIG. 2.

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When the fluid pumped into the soil is a cement slurry, a continuous subsurface wall is constructed throughout the traversed volume simultaneously with the cutting action. That is, as the cement slurry exits the ports or jets 24, it cuts the soil and mixes with it, but this mixture is retained in place by the adjacent uncut soil outside the path of the beam 4. Upon curing or hardening of this mixture, the continuous subsurface wall provides a containment barrier such as for contaminated material buried in the adjacent uncut soil.

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It is contemplated that the high pressure fluid alone can be sufficient to produce enough cutting action for the beam and conduit to advance into the soil. It is also contemplated that additional means can be used. For example, the beam could be vibrated or other mechanical techniques could be used to generate or facilitate the forward motion of a thin subsurface member. The preferred embodiments of the present invention include means for reciprocating the conduit 22 so that the jets 24 are moved back and forth across the soil to be cut. This means can be implemented either to reciprocate both the beam 4 and the supported conduit 22 relative to the soil or to reciprocate the conduit 22 relative to both the beam 4 and the soil 2. An illustration of the former is shown in FIGS. 2, 4 and 5, and an illustration of the latter is shown in FIG. 7.

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The reciprocating means of FIGS. 2, 4 and 5 includes a hydraulic cylinder assembly 34 having one end connected to the beam 4 and having its other end connected to the

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frame of a crane 36 embodying the support 6. These connections can be by any suitable means known in the art, but in the illustrated embodiment the end connected to the crane 36 is connected by means of a trunnion 38.

5 The hydraulic assembly 34 includes two hydraulic cylinders 40, 42 and a centering box slide with wear plates collectively marked with the reference numeral 44. The cylinders 40, 42 are operated from the cab of the crane 36 through hydraulic control lines 45. This

10 control extends and retracts the cylinders through whatever length of stroke for which the cylinders are designed (e.g., 5 feet to 20 feet). The beam 4 and its mounted conduit 22 follow this movement to stroke along the adjacent soil. This ensures complete coverage of the

15 soil by the jets 24 and their ejected high pressure fluid.

An alternative to the foregoing embodiment of the reciprocating means is illustrated in FIG. 7. In FIG. 7,

20 the beam 4 is not reciprocated (but it is still free to pivot where it is attached to the support 6), but the conduit 22 and its jets 24 are moved back and forth along the beam 4 and the adjacent soil. The conduit 22 can be mounted on pulleys 46 to facilitate its movement. The

25 ends of the conduit 22 are mounted on reels 48, 50 which are operated by a controller 52. The controller 52 can be implemented in a known manner to synchronize the reels 48, 50 and the back and forth movement of the conduit 22. Groups of jets 24 are spaced to accommodate the stroke

30 length of the back and forth movement so that the entire soil area adjacent the length of the beam 4 is covered during each reciprocation. Fluid is communicated into the conduit 22 by the hoses 30, 32 connected in a known manner with the ends of the conduit 22 on the reels 48,

35 50.

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Th embodiment illustrat d in FIG. 7 can be implemented in other ways. Steel or other suitable material cables connected to the conduit 22 can be mounted on the reels 48, 50 so that the reels wind and
5 unwind the cables to move the conduit 22 rather than winding and unwinding the conduit ends directly. In an alternative embodiment, the high pressure fluid can be provided through a flexible hose contained within the interior cavity of the beam 4 filled with a dense fluid
10 to allow movement of the hose and give sufficient weight to the beam 4 to prevent it from having buoyancy.

The means for creating cutting action of the embodiment shown in FIGS. 2-5 further includes one or
15 more mechanical cutter members connected to the beam 4. One type is shown in FIG. 3. This type includes a plurality of serrated blades 54 pivotally connected to the beam 4. Another type is illustrated in FIGS. 2 and 5. This type includes a plurality of saw teeth 56
20 connected to the beam 4. As used herein, "connected to" includes being formed as an integral part of the beam 4 or other object. Regardless of the particular manner in which the mechanical cutter members are implemented, they are preferably disposed to cut a path at least slightly
25 wider than the main body of the beam 4 to facilitate movement of the beam 4 through the cut soil.

As previously described, movement of the beam 4 occurs at least in response to gravity as the beam 4
30 sinks into the cut, fluidized soil. In the illustrated embodiment, the beam 4 is also moved by the support 6 shown in FIG. 2 specifically implemented by a conventional crane 36. As the crane 36 moves to the right as viewed in FIG. 2, it advances the beam 4 and the
35 conduit 22. This is d n even whil the beam 4 and/or conduit 22 are b ing reciprocated. Referring to FIG. 1,

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gravity can move the beam and conduit through sector 58 of the soil 2, and a mobile support 6 can move them through the volume which includes the area 60. In practice the beam and conduit typically will be transported by the support 6 so that an acute angle 62 (e.g., 45 degrees) to vertical is maintained.

In the FIG. 2 embodiment, a line 64 from the crane 36 implementing the support 6 is connected to the beam 4. The line 64 is typically slack during operation of the apparatus, but it can be used to lift the beam and conduit assembly if desired.

Although the support 6 is used in the preferred embodiments described herein, it is contemplated that it is not required. That is, it is contemplated that the beam and conduit can be used without the support 6 when sufficient cutting action can be obtained with the high pressure fluid alone. For example, a beam of desired length can be laid along the ground and high pressure fluid pumped through the ports of the conduit to create the cutting action. As this occurs, the beam and conduit will sink. If the fluid is a cement slurry, for example, a wall will be constructed above the sinking beam and conduit. When the beam and the conduit are at the desired depth, pumping is stopped and the hoses extending into the ground to the ends of the conduit are cut or otherwise disconnected. The beam and the conduit are left in the soil at the bottom of the wall.

It is to be noted that "beam" as used in the foregoing and other embodiments described herein can in general be anything which advances into the cut soil to remain adjacent the face of initially uncut soil in response to gravity. This includes the previously described H-beam structure, but it includes other

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embodiments as well. It is contemplated that the "beam" can be implemented by a flexible member, such as a hose, which is made rigid by the fluid pumped through it. The material of the flexible member and the composition of the fluid should be such that their combined weight is sufficient to make this form of beam sink or advance in the needed manner. This latter type of beam would thus implement both the beam and the conduit. Another form of initially flexible beam can include concentric hoses or members. The inner structure would be filled with any needed weight-increasing material, and the annulus formed between the inner and outer members would conduct the high pressure fluid to be ejected through the ports or jets in the outer member.

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Additionally, a "beam" as used herein can include multiple components. This refers not only to multiple pieces as the segments 10 and plates 12 shown in FIG. 3, but also to multiple overall beam structures. For example, two beam structures are represented in FIG. 6. Each of these is similar to the beam 4 of the embodiment described hereinabove with reference to FIGS. 2-5. The two beams 4a, 4b of FIG. 6 are connected to respective reciprocating means at the surface (not shown, but these can be the same as the hydraulic cylinder assembly shown in FIGS. 4 and 5). The lower, free ends of the beams 4a, 4b are linked by a sliding link 66 to prevent these lower ends from moving laterally away from each other as the beams advance into the soil. The illustrated link 66 is implemented by a pin 68 connected to the beam 4b and passing through a slot 70 formed in the beam 4a. This construction is contemplated to be analogous to the oppositely reciprocated blades of an electric knife. Additional beams can be used. The number is contemplated to depend on the desired width of the cut to be made (e.g., 12 inches or greater).

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Referring to FIG. 2, the operation of the embodiment shown therein will be described. The operation of other embodiments described hereinabove will be readily apparent from the following description as well as from the descriptions given hereinabove.

The apparatus shown in FIG. 2 can be transported to a site in modular sections, such as 401 H-shaped beam sections and suitable lengths of conduit sections. The beam and conduit can be assembled at the site to the desired length (e.g., 401-1501 as can be suitable for a contaminated material containment wall). A shallow (e.g., 31 deep) pilot trench 72 is cut in a known manner, and the assembled beam and conduit are laid in it. The fluid is made and pumped from the vehicles 26, 28, and the fluid is injected into the soil through the jets 24. The beam 4 and/or the conduit 22 are reciprocated. As this occurs, the beam and the conduit descend as the soil beneath them is liquefied if the ejected fluid is liquid. The crane 36 moves to advance the subsurface structure. If the fluid is a cement slurry, the liquefied soil will harden to form a wall, such as a low permeability cut off wall for impounding contaminated subsurface material. Any suitable fluid can be used. For example, various admixes can be used to impart plasticity or chemical resistance to the final material. Specifically regarding material for constructing a subsurface containment wall, examples of fluids include cement slurry, latex polymer cement, bentonite clay slurry, hot wax, hot asphalt, hot polyethylene or gelled water. Other things can be emplaced with the present invention, such as a drain pipe for use as an interceptor of leaching contaminants.

The high pressure water, mud, cement slurry or other fluid is ejected from the jets 24 so that the resultant kinetic energy disrupts and erodes the soil into finely

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divided particles which are intimately mixed with the jetted fluid. The jetted fluid does not have to pass through much intervening fluid or material in the preferred embodiments so that little of the kinetic energy is lost before it impacts the soil. This is accomplished by the continuous advancement of the subsurface structure in response to gravity whereby the beam and the conduit are maintained against the face 16 of the initially uncut soil 2a. In a particular implementation of the preferred embodiment, the jets 24 are kept within about 4 inches of the face 16. This closeness is important because the kinetic energy of the fluid diminishes roughly proportional to the square of the distance in inches between the jets and the soil.

15

Once a desired length of subsurface volume has been cut, a turn such as a right angle corner can be made by allowing the subsurface structure to fall to a near vertical position or by removing the subsurface structure from the ground and intersecting the previous cut.

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From the foregoing, the method of the foregoing preferred embodiments broadly comprises generating cutting action along an extended locus of soil; and advancing the cutting action along a descending locus of the soil in response to gravity. Generating cutting action includes pumping a fluid through the conduit 22 having the plurality of ports 24 through which the fluid is ejected for injection into the soil adjacent which the conduit is disposed. If the fluid is a cement slurry, for example, the fluid injected into the soil forms a wall throughout the locus traversed by the cutting action. As the fluid leaves the jets, its high pressure is converted to kinetic energy to cut the soil and mix with the resulting particles to produce a fluidized mixture. The cutting action is achieved by reciprocating the jets or

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the entire conduit 22 while pumping the fluid. Reciprocating the conduit can be accomplished by moving the beam 4 with the conduit 22 or by moving the conduit 22 relative to the beam 4. In either case, the ports 24 of the conduit 22 are moved along the locus of soil to be cut so that the ejected fluid impacts across the initially uncut face 16 of the soil.

A new initially uncut face 16 is continually encountered because the method of the foregoing preferred embodiments includes the aforementioned step of advancing the cutting action. In these preferred embodiments this includes pivoting the beam 4 through a sector which can be part or all of the sector 58 depicted in FIG. 1. The beam 4 pivots at the point or points of connection to the support 6, and it pivots from its initial placement along a length of soil such as in the pilot trench 66. Pivoting occurs downwardly from this position in automatic response to gravity as the underlying soil is cut and fluidized. In the preferred embodiments, the method also includes advancing the cutting action horizontally from the descending locus and sector 58, such as by pulling the beam 4 horizontally with the crane 36.

The following examples provide a comparison between a conventional jet grouting technique and the invention of FIGS. 1-7 as a means of estimating the production rate of such invention.

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Example I

Jet grouting data supplied by Halliburton Services indicate that a pair of 2 millimeter diameter jets on a rotating 2 inch diameter shaft can produce a 12 inch diameter column at a rate of 2 seconds of dwell for each

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1.5 vertical inches f r m d. This is based on jetting cement slurry at 5000 pounds per square inch at 10 gallons per minute and 35 hydraulic horsepower per jet. In each seconds the pair of jets erodes about 165 cubic inches of soil. Each single jet erodes about 41 cubic inches of soil per second or about 86 cubic feet of soil per hour per jet. This rate of production is very conservative and is based on hard soils.

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Example II

The configuration of the present invention studied included a 100 foot beam with a 20 foot stroke and 17 jets (each having a 2 millimeter diameter as in Example I). With a 600 horsepower pumping unit, a production rate of about 1460 cubic feet of soil per hour can be obtained. For a 6 inch wide by 60 foot deep trench cut, this would traverse about 49 linear feet per hour. A 12 inch thick wall would progress about 24 feet in an hour. This does not include the mechanical cutting component of the invention which is contemplated to enhance at least slightly the process rate. The mechanical lift and cut system is estimated to require a 100 horsepower hydraulic power unit to reciprocate the beam and 6 mechanical cutters at a minimum rate of 3 strokes per minute (1 foot per second vertical travel speed). The reciprocation speed should be fast enough to limit the jet penetration to 4 inches per pass for preferred efficiency. The jets would be discharging 1364 cubic feet of cement slurry per hour, or .73 cubic feet of slurry for every cubic foot of trench. In soft soils this volume would be reduced due to the faster cutting rate. Since most soils contain only about 30 percent void space, it is expected that the trench would fill and v rflow a volume of material equal to half the trench volume. In at l ast some projects, this waste slurry could be pumped to a holding ar a and

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allowed to harden as cap r fill material. In cases where the slurry is potentially contaminated with hazardous wastes it would be "conditioned" and filtered by screen and hydrocyclone units to remove solids larger than 0.1 millimeter and recirculated to the jets along with fresh cement slurry. Equipment capable of this is routine in the drilling fluids industry.

At the productivity rates described above, the present invention is capable of producing about 1460 square feet of 12 inch thick by 60 feet deep cutoff wall per hour. Equipment which may be required to accomplish this includes: dual Halliburton Services HT-400 RCM pump truck (4.7 bpm at 5000 psi); 1400 cu. ft. bulk cement storage bin; drilling mud desander/desilter unit; office/decontamination trailer; 60 ton crane; 100 foot long jetting beam (19000 lbs.); 2 inch diameter x 5000 psi jetting hose (200 feet); and 3 mountain mover hydraulic power units.

The foregoing provides a technique by which discrete walls and/or containment barriers can be constructed. In a preferred embodiment a complete containment barrier is constructed both around and under a selected site during a single continuous operation.

Referring to FIG. 8, a contaminated waste site 100, for example, exists in the ground having surface 102. Surrounding the site 100 prior to use of the present invention is whatever substance or substances exist or have been emplaced in the ground, which substance or substances are encompassed by the term "soil" as used herein. Once the present invention has been used at the site 100, a barrier or basin 104 will extend around and under the site 100 within the soil. The barrier 104 can have various configurations, such as, without limitation,

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the five-sided shape shown in FIG. 8 or a continuously curved bowl-like shape. A cap above the site can be added in a known manner so that the site is thus fully encased.

5

The apparatus by which the barrier 104 can be constructed comprises means for cutting a continuous elongate trench through the soil from one side of the site 100 to another side of the site 100 without intersecting the site 100. It also comprises means for displacing the means for cutting through the soil so that the elongate trench is extended transversely to itself across a continuum along and under the site 100. The apparatus further comprises means for placing a barrier material in the transversely extended elongate trench. In the FIG. 8 illustration, an initial elongate trench is represented by the solid-line rectilinear shape 106. The means for creating in situ this initial continuous cross-sectional portion of the barrier 104 is then moved to transversely extend the trench continuously through the volume marked by sectors 108, 110 and partial cylinder 112, through the volume of side and bottom planar regions 114, 116, 118, and through the volume of end planar region 120.

25

An apparatus for constructing the shape of barrier 104 shown in FIG. 8 is illustrated in FIGS. 9 and 10. The apparatus of FIGS. 9 and 10 includes a rectilinearly arced support frame assembly 122 made of two parallel side support members 124, 126 and a cross support member 128 connected between and perpendicular to the lower ends of the two side support members 124, 126; however, it is contemplated that other geometries and relative positioning between the side support members and the cross member can be used. The side support members 124, 126 are disposed on opposite sides of the site 100, but

35

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ar of the same type as described above with regard to
FIGS. 1-7; however, the previously described embodiment
wherein the conduit or jets are moved relative to the
supporting beam is preferred because of the presence of
5 the cross member 128 in the present invention. The
support members have sufficient density so that the
complete frame subassembly of the invention automatically
advances into cut soil in response to gravity.

10 Referring to FIG. 10, the cross member 128 is
preferably a cutting wing which carries a high pressure
conduit 130 with at least one jet outlet 132 directed
towards the leading edge of the wing (i.e., the side of
the cross member 128 which first encounters soil to be
15 cut). As shown in FIG. 10, the cross member 128 carries
two such conduits 130a, 130b (further references will
give only the numeral, but the different components on
opposite sides of the assembly 122 are differentiated in
FIG. 10 by either "a" or "b" suffixes). Each conduit 130
20 has a respective port 132 which can be reciprocated along
a respective half of the length of the cross member 128;
but other configurations can be used (e.g., a single
outlet for the entire cross member or a series of small
jets disposed in a special pattern that is designed to
25 induce a rotational motion at the cutting face for
obtaining more effective cutting through hard soils
wherein small fragments of rocks break off and act as
cutting tools at the face of the cut) The conduits 130
and outlets 132 are reciprocated by appropriately
30 controlling a respective cable 134 which extends from the
surface, along the respective side support member, around
suitable sleeves or pulleys 136 to the respective outlet
and then back through a similar route. Each illustrated
cable 134 includes two ends at the surface, one for
35 pulling an outlet in one direction and the other for
pulling the outlet in the opposite direction. This type

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of control is similar to that used in aircraft control systems; however, it is contemplated that other types of control (e.g., hydraulic) can be used.

5 The cross member or wing 128 is rotationally connected to the side support members 124, 126 so that the angle of attack of the wing can be controlled between vertical and horizontal by one or more cables 138 extending from the surface, along the respective side
10 support member, to a respective end of the wing member. Each cable 138 can be continuous or split and connected to provide bidirectional control at each end of the wing member, or each cable can be connected to its respective end of the wing member to provide only unidirectional
15 control with one cable operating the wing member in one direction and the other cable operating the cable in the opposite direction. It is contemplated that other types (e.g., hydraulic) of control devices can be used.

20 The cross member 128 is mechanically connected at each end by a trunnion having an internal high pressure fluid swivel, generally identified by the reference numeral 140 in FIG. 10. Each swivel 140 connects to a conduit 142 extending down the respective side support
25 member 124, 126 and to the respective conduit 130 carried on the cross member 128 as shown in FIG. 10.

 Also carried on each side support member is a respective conduit 144 connected at its lower end to an
30 outlet 146. The position of the respective outlet 146 is controlled from the surface using a respective cable 148 extending in two directions from the outlet 146 as shown in FIG. 10. One portion of each cable 148 extends directly to the surface and the other portion of each
35 cable 148 turns around a sleeve or pulley 150 at the outward end of the respective side support member.

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The conduit portions in the preferred embodiment are flexible high pressure hoses which are fully contained in the respective side support member or cross member. Each outlet 132, 146 preferably provides a jetting orifice for
5 ejecting at high speed a fluid pumped into the conduit under pressure.

Each of the aforementioned conduits is a part of the overall conduit means of the illustrated embodiment.
10 This conduit means is common to both the trench cutting means and the barrier material placing means referred to above because the conduit means conducts the fluidized barrier material under pressure so that at least a
15 portion of the material exits the one or more ports to cut and simultaneously mix with the soil, after which the mixed material hardens to provide the walls of the containment vessel.

The foregoing assembly operates in the same manner
20 as the apparatus described with reference to FIGS. 1-7 in that fluid is pumped into the conduit system and ejected from the various jetting ports at high speed to cut and mix with the soil. As this occurs, the frame 122 falls into the soil in response to gravity. The fluid is
25 pumped in a known manner as previously described. Two conventional pumping systems 152, 154 are illustrated in FIG. 9 as providing fluid through lines 153, 155 to respective sides of the frame assembly 122. With regard to the embodiment shown in FIG. 10, the pumping system
30 152 pumps into the conduits 142a, 144a, and the pumping system 154 pumps into the conduits 142b, 144b.

Once the frame assembly 122 has dropped to a desired angle from horizontal, it is moved transversely so that
35 the side members 124, 126 are pulled along outwardly of the respective sides of the site 100 and so that the

-25-

cross member 128 is pulled along beneath the bottom of the site 100. This transporting of the frame 122 is done by vehicles 156, 158, specifically cranes in the illustrated embodiment, pivotally connected to the side support members 124, 126, respectively, in the same manner as described hereinabove with reference to FIGS. 1-7. That is, there are two above ground ends of the frame assembly 122, and one of these ends is appropriately connected to the crane 156 and the other above ground end of the frame assembly 122 is connected to the crane 158. Depth and path can be controlled by adjusting the angle of attack of the cross member 128. Throughout this process, fluid is pumped into the conduit system of the frame assembly 122 for cutting the soil and for emplacing the barrier material which is initially fluidized but which ultimately hardens to become the desired barrier structure.

Once the material for the bottom wall or portion of the basin 104 has been emplaced, the frame assembly 122 is extracted from the soil. This can be accomplished by drawing the assembly outwardly along the plane where the wall of region 120 is to be constructed. During extraction, fluid is still pumped to cut the soil and emplace the barrier material along this planar volume. Extraction is facilitated by disassembling the pieces of which the support members 124, 126 and the conduits are contemplated to be comprised as described above with reference to FIGS. 1-7.

30

Referring to FIG. 11, another embodiment of the present invention will be described. In this embodiment, a single flexible cutting member 158 is flexed into an elliptical arc by its own weight as it cuts a bowl shaped path under the waste site 100a. The cutting member 159 is similar to the vertical side supports and conduits of

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the embodiment shown in FIGS. 9 and 10. That is, it has one or more moving jet orifices which are to be reciprocated along various lengths of the support members, but it is long enough to be flexible. Movement of the orifices is made via steel (or other suitable material) cables which are operated from tractor units 160, 162, such as conventional cranes, on the surface in the same manner as in the embodiment of FIGS. 9 and 10. By way of example, the cutting member 159 can include a conduit framed in a steel box of rectangular cross section, which box is long enough to behave elastically. The void space in the box is filled with a dense fluid to prevent buoyancy. An opening in the box permits fluid ejected from the conduit to cut and mix with the adjacent soil.

The flexible member 159 is initially laid in an elliptical trench or path on the surface. As the jetting action begins when fluidized barrier material is pumped from the pump trucks 164, 166, the soil is cut and mixed with the fluid and the loop made by the member 159 begins to drop through the cut soil, pivoting relative to the tractor units 160, 162 to which the two ends of the loop are connected. This is continued until the loop reaches a desired angle (e.g., 45 degrees). The tractor units 160, 162 then begin advancing at a selected rate to allow the loop to maintain a preferably 30 to 60 degree angle to vertical. Raising the tool back to the surface after completing its path under the waste site 100 can be accomplished by intersecting an existing slurry trench, displacing the dense fluid in the tool with air, or by shortening the cutting member in stages.

Referring next to FIGS. 12 and 13, the embodiment illustrated in these drawings is similar to the embodiment of FIG. 11 except that the entire arcuate

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cutting member 168 of the embodiment of FIGS. 12 and 13 is reciprocated instead of just the orifices thereof. The cutting member 168 includes a flexible steel (or other suitable material) conduit, such as a string of coupled pipe sections, of sufficient wall thickness (e.g., 2' to 4') and cross-sectional width (e.g., by incorporating a stabilizer tail 170 shown in FIG. 13) to provide directional control. The jetting orifices are suitably spaced (e.g., 25' to 100') along the length of the member 168.

The entire member 168 is reciprocated through the resultant trench by the tractor units 172, 174 located on each side of the waste site 100b beneath which the basin is to be formed. Each tractor unit in this embodiment preferably includes a side boom pipeline tractor equipped with a powered member handling unit capable of pushing or pulling the member 168 in 100' strokes in concert with the opposite unit. As reciprocation occurs, fluidized barrier material is pumped under high pressure (e.g., 2000 psi to 5000 psi) into either or both ends of the member 168 from conventional pump trucks 176, 178 suitably connected to one or both ends of the conduit as in the other embodiments.

25

If the member 168 wears sufficiently that it needs replacing, the entire member 168 can be pulled out one end of the trench while a new member is pulled in from the other end. To try to reduce wear, the fluidized barrier material ejected from the orifices of the member 168 can include one or more substances which lubricate the outer surface of the member 160.

Although the size of any of the foregoing embodiments is not necessarily theoretically limited, it is contemplated that the embodiment of FIGS. 12 and 13

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may be most suitable for long working distances (e.g., 400' to 800', whereas the embodiments of FIGS. 9-11 may be practical only up to 200' to 500', for example). Such long distances may be encountered in containing very large sites such as mining waste piles. The last described embodiment (FIGS. 12 and 13) also has relatively low cost subsurface components (in its simplest form, it can be only a pipe string having jetting orifices), thereby requiring possibly less capital investment.

The apparatus shown in FIG. 14 is a preferred embodiment for cutting soil and forming subsurface containment barriers. The support 5 is a telescoping boom excavator, such as the Gradall 880 excavator. A pilot trench 72 is cut in known manner. A source of fluid is provided by lines 30 and 32 to the top of the beam 4 which is also the conduit for the means for creating a cutting action. The fluid lines 30 and 32 are preferably connected to high pressure pump 34 and grout plant 36 in order to provide a high pressure grout slurry. The beam 4 is preferably a heavy wall steel pipe which comes in 12 foot sections with linking assembly 6 shown in more detail in FIG. 15 which shows pivot point 21 which allows beam 4 to pivot relative to boom 9, with jet port area 7 shown in more detail in FIG. 16 which contains a plurality of jet ports across its width and a cutter 22 which breaks up small obstructions contacted in its reciprocating movement, and failing that will stop the conduit and direct the force of the jet streams against the obstruction until it is destroyed. Shield 23 helps eliminate sharp edges and possible snags on obstructions at this point on the beam 4. End jet port area 8 is shown in more detail in FIG. 17 and contains jet ports to cut at different angles from the axis of beam 4 in order to cut away obstacles that might

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interfere with the end of beam 4 and also containing cutter 22 which serves the same function as the cutter shown in FIG. 16. Beam 4 is attached to boom 9, which comprises means for providing reciprocating action, preferably by a hydraulic cylinder with an inner cylinder structure 24 which moves in and out of outer cylinder structure 25. Cylinder structure 24 preferably comprises a cylinder and a rigidifying support structure.

Boom 9, attached to support 5, has the capability of rotating back and forth around the axis of the length of the boom which provides the capability to change the direction of the cutting action from the reciprocating jet streams in order to turn corners to shape the containment barrier being formed, to avoid obstacles, etc.

With regard to all the embodiments, mechanical cutters as shown for the embodiments of FIGS. 1-7, for example, can be affixed to the subsurface members of the present invention to aid in cutting a path through the soil, which cutting is primarily performed hydraulically in the illustrated embodiments. Additionally, it is also to be noted that the density and gel strength development characteristics of the fluidized barrier material mixed with the cut soil should be adequate to support the overburden weight of (e.g., this would begin at locus 106 in FIG. 8). This is continued while the conduit is pulled transversely to its length so that the trench is extended transversely to its length. Referring to FIG. 8, by way of example, the frame by which the locus 106 is defined sinks through sectors 108, 110 and partial cylinder 112; the frame is then pulled through the remainder of the volumes 114, 116, 118, 120. This is controlled so that the transversely extended trench extends not only alongside but also underneath the volume

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of soil or material within the confines of the resultant basin. Pulling of the conduit occurs either or both automatically in response to gravity due to the density of the conduit or its support or mechanically in response to movement of a suitable vehicle such as a crane or other suitable tractor unit.

Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned above as well as those inherent therein. While preferred embodiments of the invention have been described for the purpose of this disclosure, changes in the construction and arrangement of parts and the performance of steps can be made by those skilled in the art, which changes are encompassed within the spirit of this invention as defined by the appended claims.

The soil cutting according to this invention is preferably accomplished by rapidly moving the fluid jet streams from the cutting means of the apparatus of this invention across the face of the soil being cut so as to force all the cutting action to occur within 80 jet diameters of the jet orifice or port, and more preferably within 30 jet diameters. Cutting efficiency drops off exponentially with increasing distance between the soil to be cut and the jet orifice or port. For example a .078 inch diameter jet nozzle operating with 5000 psi fluid should cut 4 times as many cubic inches per second at 4 inches as it does at 8 inches away from the target soil. To keep the fluid jet streams from penetrating too far into the soil with common soils it is preferable to move them at linear velocities from 1 to 6 feet per second, with 2 to 4 feet per second being more preferred.

The diameter of the fluid ports of this invention may vary over a wide range. However, with preferred

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fluids port diameters between .078 inch and .156 inch are preferred. Using standard 900 horsepower pumping units, jet ports of a smaller diameter are operable. However, smaller diameter jet ports are also more prone to plugging and must be moved at a faster speed. Since there are a finite number of jet streams that can be produced, the jet ports must be spaced more widely as the depth or cutting face area increases. The length of the stroke of the reciprocating mechanism which moves the jet streams across the soil to be cut may be from about 4 feet to about 40 feet long with 8 feet to 16 feet being the preferred stroke length to be compatible with existing telescoping boom excavating equipment. Shorter strokes require greater numbers of jet streams and smaller diameter jet ports.

The high pressure fluid used to cut and modify the soil is preferably pumped at pressures from about 400 psi to about 10,000 psi, with 2000 psi to 5000 psi being more preferred in common soil types.

The weight of the cutting means in a slurried soil is preferably sufficient that at any given operating angle the reaction thrust of the jet streams is less than the forward thrust due to gravity.

The soil cutting method and apparatus of this invention can be practiced with any type of support or carrier such as a crane, tracked backhoe, cherry picker, tractor, truck, or a dozer. A preferred support is a telescoping boom excavator such as the Gradall 880 excavator for moderate depths of about 70 feet. This unit is preferred because it has a powerful reciprocating mechanism. This eliminates the need to add this capacity to the support. The Gradall excavator's ability to rate the conduit of the cutting means is also desirable

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for turning corners in the soil with the apparatus of this invention. A special hydraulic valve package may be added to this unit to automate both the reciprocation and the travel of the carrier.

5

The preferred apparatus consists of a network of electric solenoid valves which, when activated, for example by a push button, cause the beam 4 of FIG. 14 to automatically reciprocate at top speed. Moving any of the standard joystick controls will shut off the automatic mode and restore normal operation. When in the auto stroke mode the movement of the excavator is controlled by a sensor mounted on the end of the boom. When the beam 4 of FIG. 14 falls to a specified angle with respect to the boom 9 the tracks are automatically activated to move the excavator several inches backward (but in the direction that the soil cutting is proceeding). This tends to keep the beam 4 and the boom 9 parallel or at a preset angle with respect to each other. A gravity reference angle sensor mounted on the non-reciprocating portion of the boom 9 allows the operator to set the angle of the boom in order to exercise a degree of control over the depth of operation.

25

The preferred soil cutting apparatus of this invention can be operated with any type of pumpable fluid. A fluid which will set up into an impermeable barrier is preferred. Especially preferred are those which will form long lasting barriers, such as Portland cement based fluids. Such a fluid preferably contains particles no larger than about $1/3$ the diameter of the jet port. The preferred fluid for forming impermeable walls is a mixture of Portland cement, bentonite, or flyash with water. The final wall material is preferably formed from 1 part jetted slurry and from $1/2$ to 2 parts original soil. The slurry composition is preferably

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designed to give acceptable final properties within a wide range of soil loadings. Other materials such as hot wax or polymer grout can also be used. Polymer gelled water may be used when it is desired to form a temporary
5 slurry filled trench wherein a drainage pipe is laid and the trench filled with permeable material for the purpose of intercepting and recovering contaminated groundwater.

The cutting means of the apparatus of this invention
10 preferably comprises one or more conduits for high pressure fluid, preferably weighing from about 50 to about 150 pounds per linear foot with 80 to 120 pounds per foot being most preferred for common soils where a 12
15 inch wide wall is to be formed. The cutting means may be relatively flexible or relatively rigid, with greater rigidity being preferred to make monitoring of operating depth more accurate. The spatial orientation of the jet
20 streams may take many forms but the preferred form is to have a transverse row of 5 to 7 jet streams covering a width of 12 inches. These jet streams are preferably perpendicular to the axis of the conduit of the cutting means.

In a preferred embodiment this row of jet streams is
25 repeated every 12 feet of the length of the conduit. An additional group of jet streams is preferably added on the bottom end of the conduit of the cutting means which is angled 45 degrees forward to aid in cutting into hard formations. The diameter of the jet ports chosen for any
30 particular row may be varied according to the hardness of the soil at that level. The conduit may be fabricated in one or more pieces but the preferred method is to fabricate the conduit in modular 12 foot long sections with the rows of jet streams mounted in replaceable
35 holders every 12 feet of conduit length.

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At each row of jet streams it is preferred to have a knife edged protrusion (cutter) which is intended to catch on any solid obstructions which are encountered on the downward stroke of the up and down movement of the reciprocal movement of the cutting means. The cutter serves to break up small obstructions or failing that it will stop the conduit and direct the force of the jet streams against the obstruction until it is destroyed.

The diameter of the conduit of the cutting means preferably varies in size, being significantly smaller generally compared to the diameter of the area where the jet ports are located, in order that rocks and debris which are loosened by the jet streams may readily pass around the relatively small diameter conduit. This may be accomplished by adding a truss to the arm of the cutting means with large openings to allow for the passage of rocks and debris. Preferably for a saw which cuts a 12 inch wide path and has a modular jet port area which is 12 inches wide connected to a body of heavy wall steel pipe. A preferred steel pipe contains a 6.5 inch outside diameter and a 3 inch inside diameter.

The flow rates of the fluid through the conduit of the apparatus of this invention preferably vary from about 50 gallons per minute to about 1000 gallons per minute, and more preferably from about 200 to about 600 gallons per minute.

The cutting means of this invention may also include a vibrating in place of the conduit for transmitting fluids to form reciprocating fluid jet streams. The vibrating beam cuts the soil by the combination of resonant vibrations, the shape and size of the beam and the weight of the beam per unit length of the beam. A hardening fluid is pumped down a smaller conduit attached

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to the beam. This fluid is mixed into the soil by the vibration of the beam.

5 In addition to obtaining downward force by means of gravity downward force may also be applied mechanically or hydraulically, or by pulling a trailing cutting means angled downward into the soil forward through the soil by means of a tractor or other carrier means. By locking the angle of the cutting means to ground in place as the
10 cutting means is pulled forward additional downward force is applied to the cutting means.

For very deep cuts into the soil, such as over 25 feet in depth, the use of gravity to increase the
15 downward force into the soil is increasingly important since it becomes difficult if not impossible through normal soils due to strength of materials and the limited power of carriers to pull such cutting means through the soil at all, or to do so without bending or otherwise
20 distorting the cutting means out of shape.

Common soils for best results of the applications and methods of this invention are sandy soil, loam, moist clay, gravel and combinations thereof. Baked clays,
25 hardened Texas gumbo, solid rock or the like are generally not acceptable. However, the preferred fluid cutting of this invention can cut through steel pipe and very strong debris materials when the various cutting parameters are optimized for cutting through such
30 materials according to the normal skills of this art.

CLAIMS:

1. An apparatus for cutting soil, comprising:
 - 5 a support;

abutting means, pivotally connected to said support,
for abutting an extended length of soil in
response to gravity; and
 - 10 cutting means, for creating a cutting action against
the extended length of abutting soil.
- 15 2. An apparatus as defined in claim 1, wherein said
cutting means additionally comprises moving means for
rapidly moving said cutting means against the extended
length of abutting soil.
- 20 3. An apparatus as defined in claim 1, wherein said
means for creating a cutting action includes a conduit,
said conduit including a plurality of ports through which
a fluid pumped into said conduit is ejected against
- 25 abutting soil.
4. An apparatus as defined in claim 3, wherein said
cutting means further includes reciprocating means for
- 30 moving said conduit so that said ports are reciprocated
along the abutting soil.
5. An apparatus as defined in claim 4, wherein said
- 35 cutting means further includes pumping means for pumping
a cement slurry through said conduit and said ports.

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6. An apparatus as in claim 1 additionally comprising vibrating means for vibrating said cutting means along the length of cutting means and adjacent to the length of abutting soil.

5

7. An apparatus as in claim 1 wherein said support additionally comprises means for applying additional force on said cutting means in a desired direction to move said cutting means through the soil.

10

8. An apparatus as in claim 4 wherein said support comprises transport means for moving said apparatus across an area of soil to form the desired cut or containment barrier in the subsurface of the soil.

15

9. An apparatus as defined in claim 8 wherein the forward progress of the support means occurs in response to a signal from a device which senses changes in the angle between said conduit and the boom containing said reciprocating means.

20

25

10. An apparatus for cutting soil, comprising:

conduit means for conducting a fluid to a plurality of fluid ejection ports of said conduit means;

30

reciprocating means for moving said conduit means so that said plurality of ports reciprocate relative to a length of adjacent soil against which said conduit means is disposed; and

35

transport means for moving said conduit means and
said reciprocating means across an area of soil
while said reciprocating means reciprocates
said ports.

5

11. An apparatus for cutting soil, comprising:

10 conduit means for conducting a fluid into soil to
cut the soil and to produce a fluidized mixture
of soil and fluid; and

15 conduit support means for supporting said conduit
means adjacent soil to be cut, said conduit
support means having a sufficient weight so
that said conduit support means and said
conduit means sink into the fluidized mixture
as the soil is cut and the mixture is produced.

20

12. An apparatus as defined in claim 11, further
comprising means for reciprocating said conduit support
means.

25

13. An apparatus as defined in claim 11, wherein said
conduit means and said conduit support means are
combined.

30

14. An apparatus for constructing a containment barrier
for a site disposed in soil, comprising:

35 means for cutting a continuous elongate trench
through the soil under the site;

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means for displacing said means for cutting through the soil so that the elongate trench is extended transversely to itself across a continuum along and under the site; and

5

means for placing a barrier material in the transversely extended elongate trench.

10 15. An apparatus as defined in claim 14, wherein said means for cutting and said means for placing include in common conduit means, including a plurality of ports, for conducting the barrier material in fluidized form under pressure so that at least a portion of the fluidized
15 barrier material exits said plurality of ports to cut and simultaneously mix with the soil, and wherein said apparatus additionally comprises means for rapidly reciprocating said common conduit means adjacent to the soil abutting an extended length of said common conduct
20 means.

16. An apparatus as defined in claim 15, wherein said site is a waste site means for cutting further includes
25 support means for supporting said conduit means, said support means having a density wherein said support means and said conduit means automatically advance into cut soil in response to gravity.

30 17. An apparatus as defined in claim 14, wherein said means for cutting includes a conduit having a plurality of fluid ejection ports, said conduit adapted to be extended under the waste site and said conduit adapted to c nduct a fluid to said port so that at least a portion
35 of the fluid exits thr ough said p rt to impact n s il adjacent which said conduit is disposed, and wherein said

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apparatus additionally comprises reciprocating means for moving said conduit so that said plurality of ports reciprocate relative to a length of adjacent soil against which said conduit is disposed.

5

18. An apparatus as defined in claim 14, wherein said means for cutting includes:

a support; and

10

conduit means for conducting fluid into the soil, said conduit means disposed on said support so that said conduit means is movable relative to said support.

15

19. An apparatus as defined in claim 18, wherein said support includes two side members and a cross member connected between said two side members, said two side members adapted to be disposed on opposite sides of the waste site.

20

20. An apparatus as defined in claim 19, wherein said conduit means includes a plurality of sections, each of said sections disposed along a respective one of said two side members and said cross member of said support and each of said sections having at least one respective port through which fluid is ejected to impact adjacent soil, each said port movable with the respective section of said conduit means relative to the respective one of said two side members and said cross member.

25

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21. An apparatus for constructing a subsurface basin in soil, comprising:

5 means for creating in situ a continuous cross-sectional portion of the subsurface basin, said means including a conduit adapted to be disposed in the soil along at least a portion of a locus extending into the soil and lying across a cross-sectional area of the
10 basin, wherein said conduit has a plurality of openings for ejecting fluid under pressure into the soil;

15 means for moving said conduit transversely to said locus; and

means for reciprocating said conduit along said locus.

20

22. An apparatus as defined in claim 21, wherein said means for creating, further includes two side support members and a cross support member connected between said two side support members, said support members having
25 said conduit disposed thereon.

23. An apparatus as defined in claim 22, further comprising a first crane having one of said side support members pivotally connected thereto, and a second crane
30 having the other of said side support members pivotally connected thereto.

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24. A method of cutting soil, comprising:

generating cutting action along an extended locus of
soil; and

5

advancing the cutting action along a descending
locus of the soil in response to gravity.

10 25. A method as in claim 24, wherein said generating
cutting action includes rapidly vibrating a beam which
abuts the extended locus of soil.

15 26. A method as defined in claim 24, wherein said
generating cutting action includes pumping a fluid
through a conduit having a plurality of ports through
which the fluid is ejected at a high velocity as jet
streams into the soil adjacent which the conduit is
20 disposed.

27. A method as defined in claim 26, wherein said
generating cutting action includes reciprocating the
25 conduit while pumping the fluid.

28. A method as defined in claim 24, further comprising
advancing the cutting action horizontally from the
30 descending locus.

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29. A method as defined in claim 26, wherein said
generating cutting action includes pumping a cement
slurry into the soil so that the cement slurry forms a
containment barrier throughout the locus traversed by the
5 cutting action.

30. A method of cutting soil, comprising:

10 placing a cutting member along a length of soil, the
member pivoted at one end to a support;

reciprocating the cutting member;

15 allowing the cutting member to pivot, relative to
the support, downwardly through a sector in
response to gravity so that the cutting member
automatically advances adjacent initially uncut
soil within the sector;

20 moving the support so that the cutting member
advances through soil beyond the sector; and

25 pumping a fluid through the conduit and the fluid
ejection ports to form jet streams which cut
and mix with the soil.

31. A method as defined in claim 30, further comprising
30 pumping a cement slurry or other types of hardening
fluids through the cutting member to mix with the soil
for creating a containment barrier across the area
traversed by the cutting member.

35

32. A method of constructing a subsurface containm nt barrier, comprising:

- 5 (a) cutting into soil along a continuous locus extending into the soil under a site which is desired to be contained;
- (b) simultaneous with said step (a), emplacing a fluidized barrier material in the cut soil; and
- 10 (c) repeating said steps (a) and (b) throughout a continuum between a first said locus and a second said locus.

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33. A method as defined in claim 32, wherein said steps (a) and (b) include moving an orifice along said locus and emitting said fluidized barrier material from said orifice so that said fluidized barrier material cuts the soil and mixes therewith for hardening into a solidified barrier.

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34. A method as defined in claim 33, wherein said step (c) includes moving said orifice transversely to said first said locus.

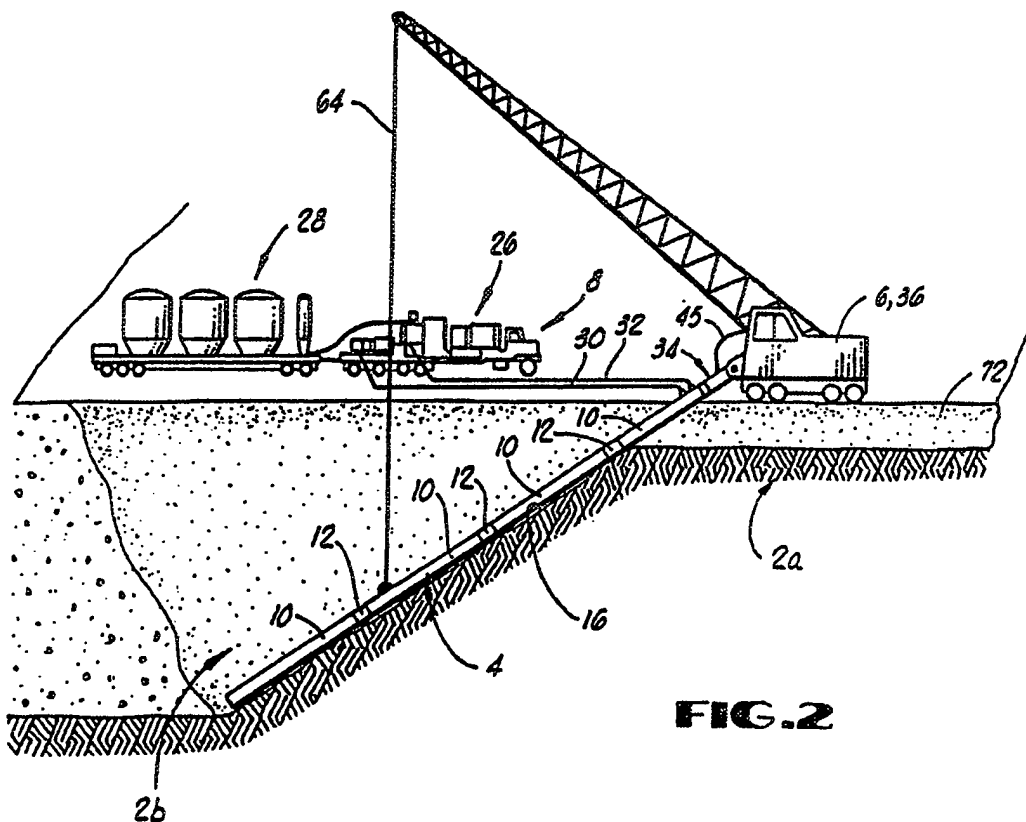
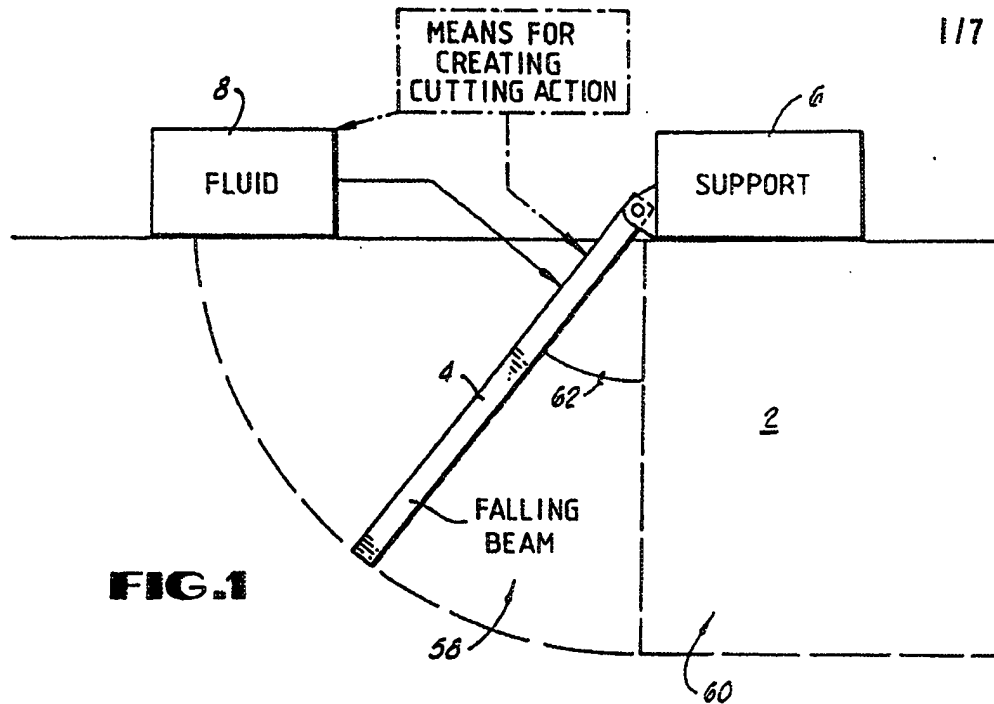
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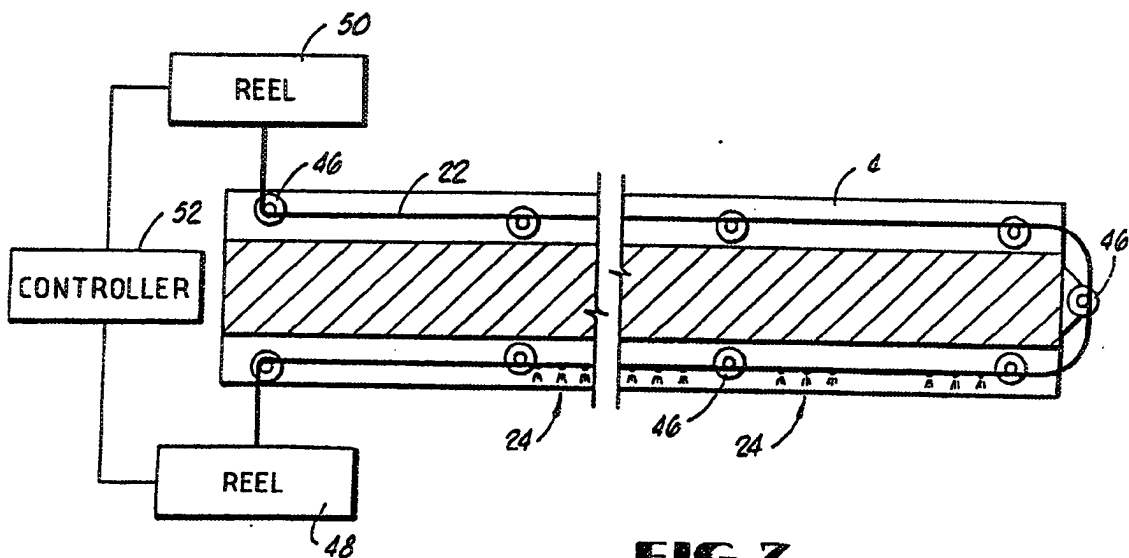
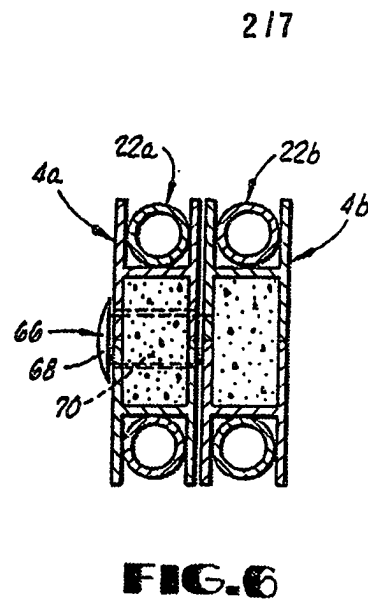
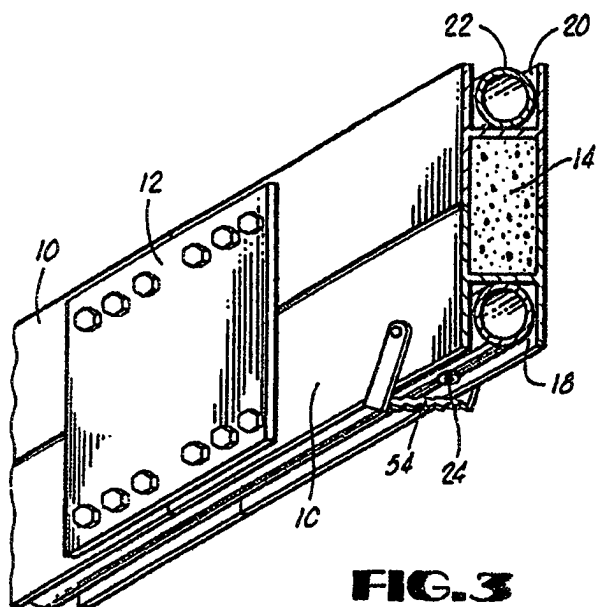
35. A method as defined in claim 32, wherein said steps (a) and (b) include reciprocating a conduit along said locus, pumping said fluidized barrier material under pressure through said conduit, and jetting said fluidized barrier material from ports defined in said conduit.

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36. The invention as described and disclosed herein.





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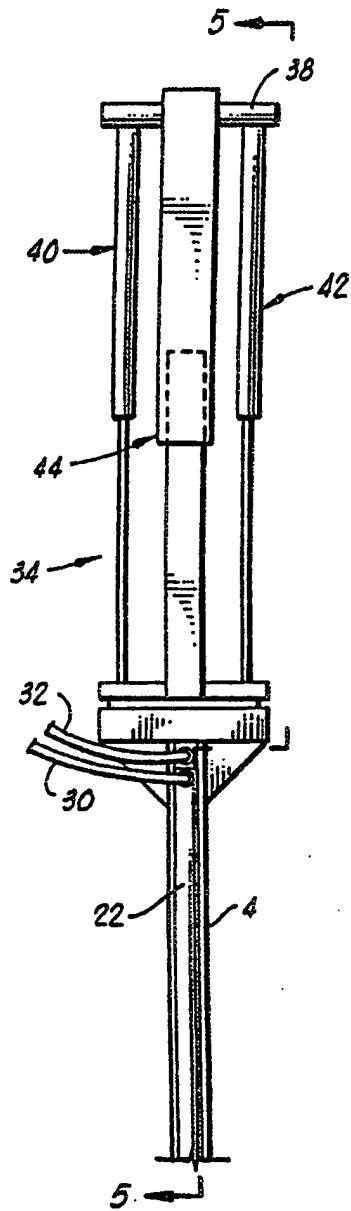


FIG. 4

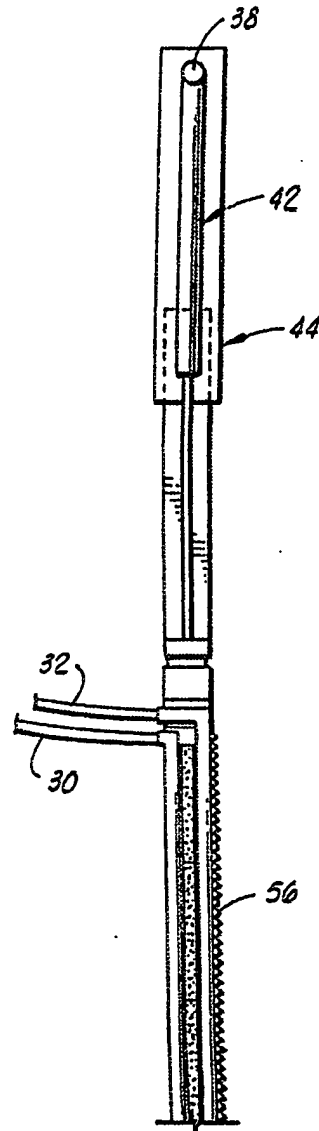


FIG. 5

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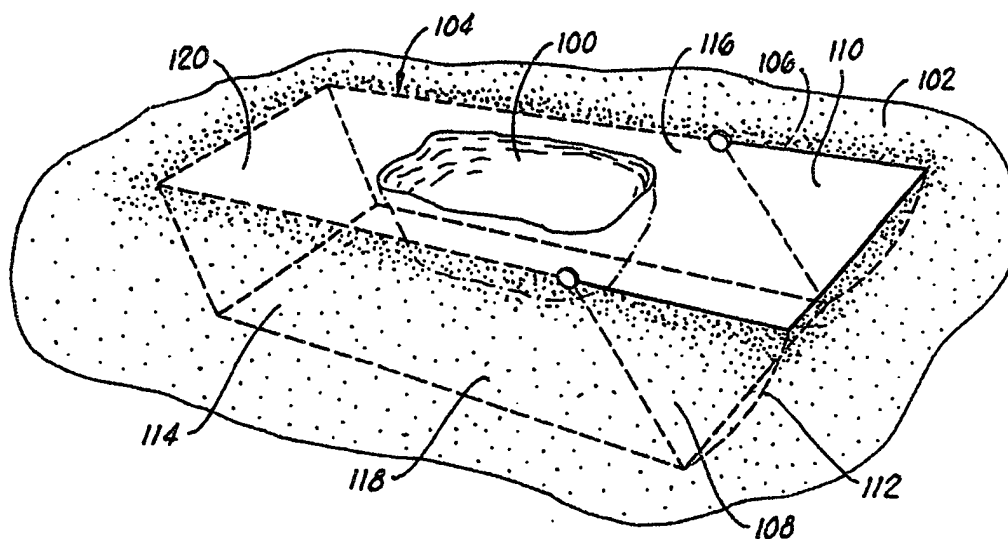


FIG. 8

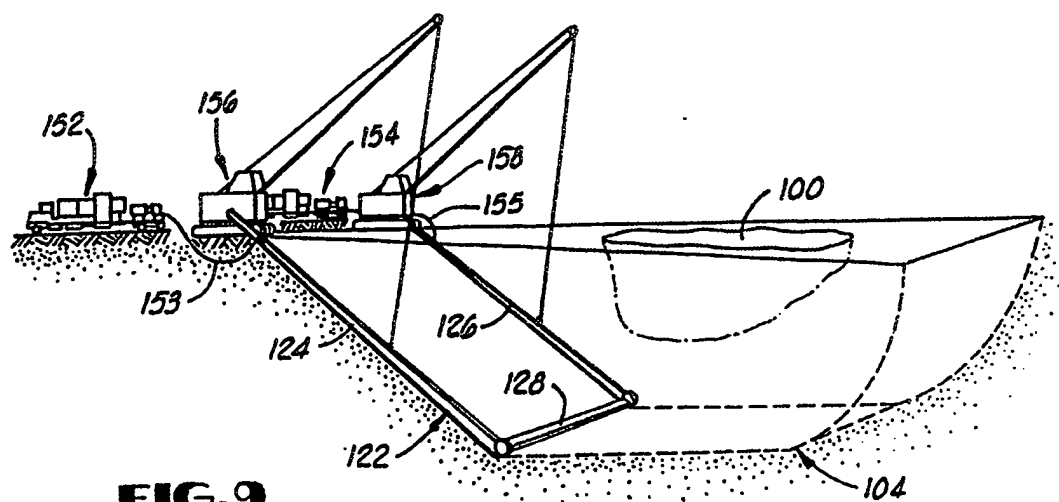
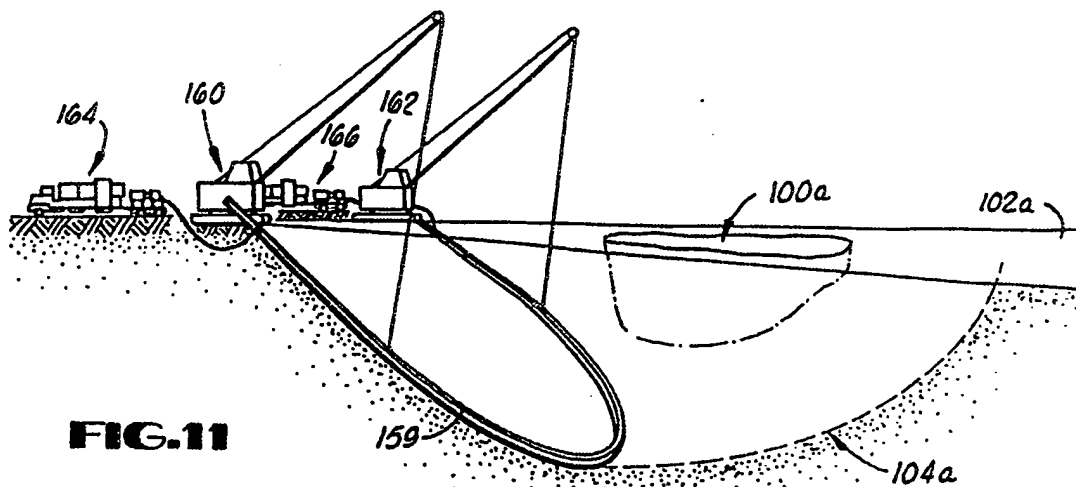
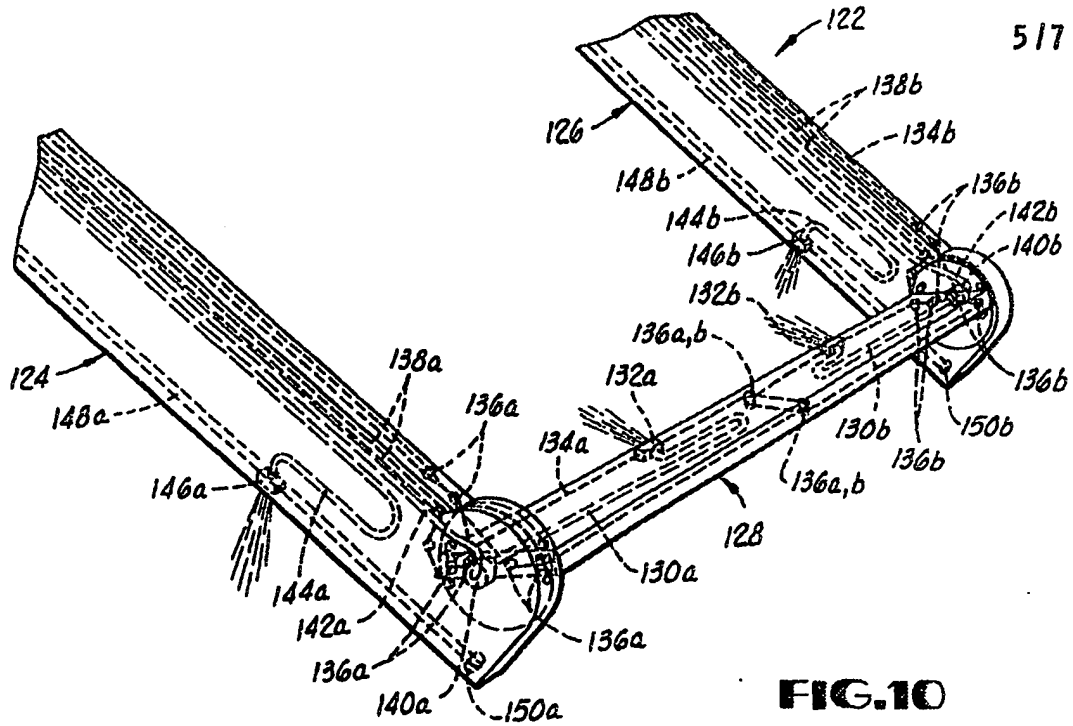


FIG. 9



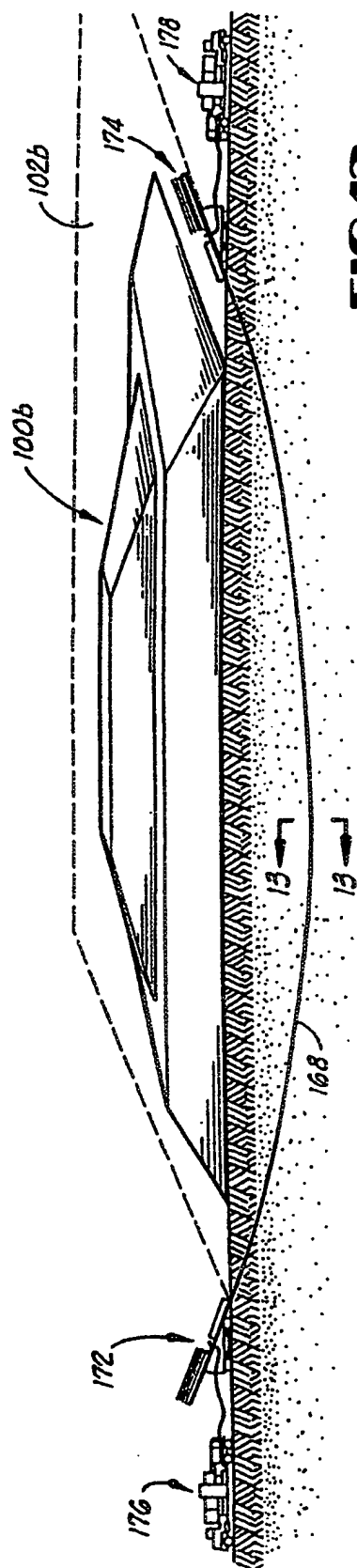


FIG. 12

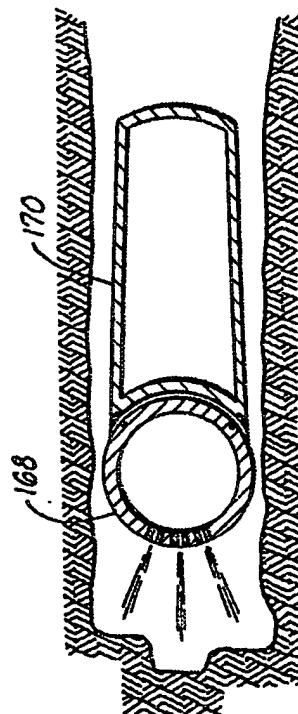
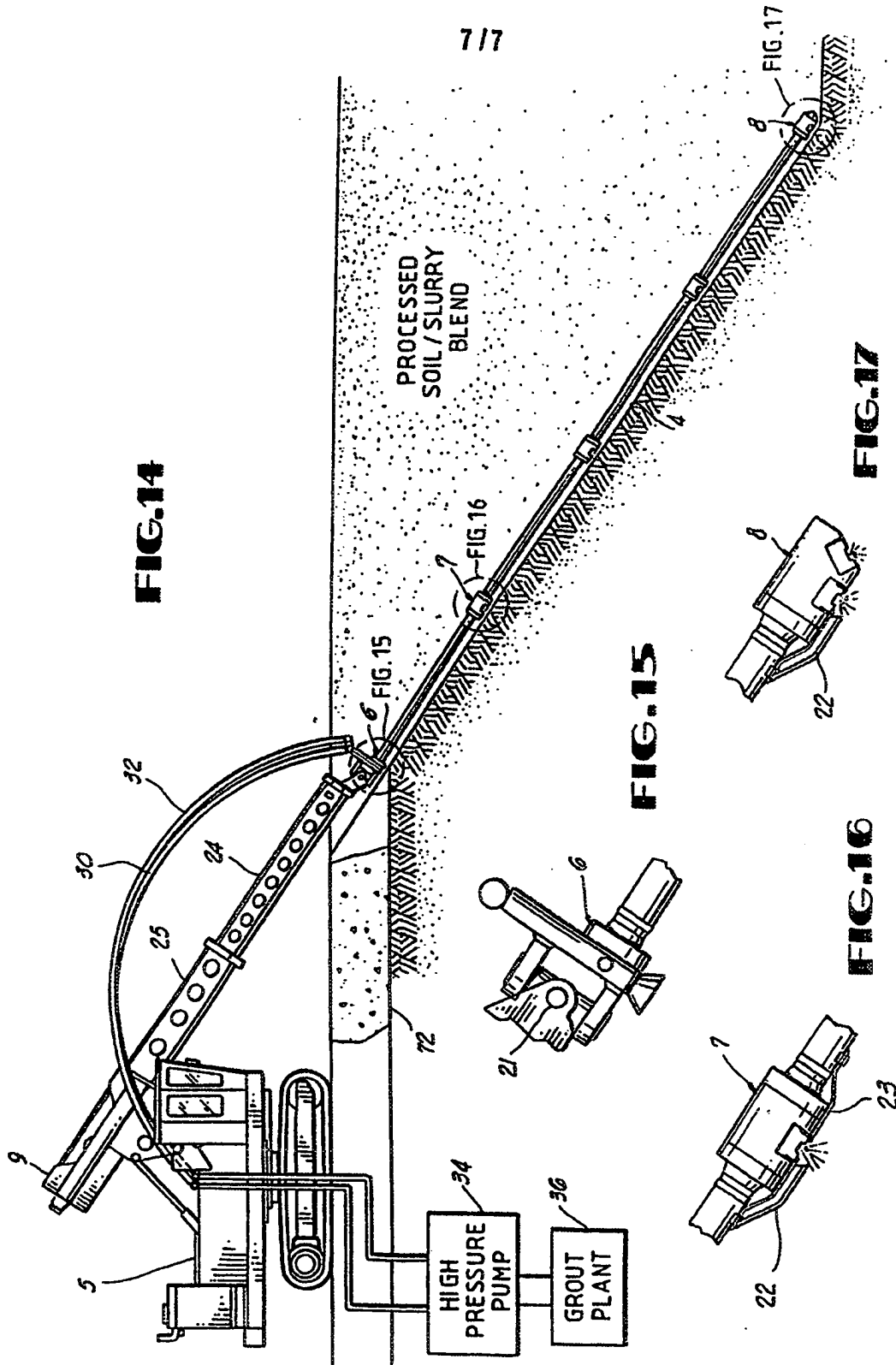


FIG. 13

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INTERNATIONAL SEARCH REPORT

International application N .
PCT/US92/05303

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :E02D 5/00

US CL :405/128

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 405/129,263,266,248,269,73,74; 175/67,17,16; 299/16,17,14,11; 37/54,75,78

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US,A, 3,132,852 (DOLBEAR), 12 MAY 1964, See fig. 1, co. 1, lines 41-57.	<u>1-5.8.10-14.18</u> 6,7,9,15,15-35
X Y	US,A, 3,645,101 (SHERARD), 29 FEBRUARY 1972, See figs. 4 & 15.	<u>1-5.8.10-14</u> 6,7,9,15-35
X Y	US,A, 4,057,969 (ROCHMANN), 15 NOVEMBER 1977, See fig. 1, col. 1, lines 40-50.	<u>1-5.8.10-14</u> 6,7,9,15-35
X Y	US,A, 4,696,607 (RESSI DI CERVIA) 29 SEPTEMBER 1987, see figures 1 & 4	<u>1-5.8.10-14</u> 6,7,9,15-35
X Y	US,A, 4,981,399 (SONG), 01 JANUARY 1991, See entire document.	<u>1-5.8.10-14</u> 6,7,9,15-35

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

23 SEPTEMBER 1992

Date of mailing of the international search report

29 OCT 1992

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